

Chapter 19

Light: Geometric Optics

19.1 Speed of Light/Index of Refraction

Homework # 151

Use the table to the right throughout the chapter. Go online for a more complete listing of [Indices of Refraction](#) and a table of [Optical Glasses](#).

I

01. What is the speed of light in _____?
a.) acetone b.) sapphire
02. The speed of light in heavy flint glass is 1.81×10^8 m/s. What is the index of refraction of heavy flint glass?
03. What is the speed of light in diamond?
04. The speed of light in methylene iodide is 1.72×10^8 m/s. What is the index of refraction of methylene iodide?
05. How long does it take light from the sun to reach the earth? Assume space is a vacuum. See [Homework #26](#) for the table of "Planetary Data" in "Chapter 4-Circular Motion and Gravitation".
06. How long does it take light from the sun to reach the Pluto? Assume space is a vacuum. See [Homework #26](#) for the table of "Planetary Data" in "Chapter 4-Circular Motion and Gravitation".
07. The distance light travels in a year through a vacuum is known as a light-year (ly). Calculate this distance known as a light-year.
08. Alpha Centauri C is the closest star to our sun, Sol, at a distance of about 4.22 light-years (ly) away. This means it takes light from Alpha Centauri C 4.22 years to reach the earth. Approximately, how far away from the earth is Alpha Centauri C as measured in meters?

Indices of Refraction ($\lambda = 589$ nm)

Material	$n = c/v$
Vacuum	1.00000
Air (at STP)	1.00029
Acetone	1.36
Benzene	1.50
Calcite	1.68
Carbon Disulfide	1.63
Diamond	2.417
Ethyl Alcohol	1.36
Glass	
Arsenic Trisulfide	2.04
Fused Quartz	1.46
Crown Glass	1.52
Light Flint	1.58
Glycerine	1.473
Ice	1.31
Lucite or Plexiglass	1.51
Sapphire	1.77
Sodium Chloride	1.53
Water	1.33

II

09. Michelson measured the speed of light to be 2.99798×10^8 m/s using a rotating eight sided mirror located on Mount Wilson and a fixed mirror 35 km away on Mount Baldy (Mount San Antonio). Both mountains were located in the San Gabriel Mountains of California. What was the minimum angular velocity of Michelson's eight-sided mirror?

ANSWERS: **01.** a.) 2.21×10^8 m/s b.) 1.69×10^8 m/s **02.** 1.66 **03.** 1.24×10^8 m/s **04.** 1.74
05. 500 s = 8.33 min **06.** 19,667 s = 5.46 h **07.** 9.46×10^{15} m = 5.86×10^{12} mi **08.** 3.99×10^{16} m
09. 3364 rad/s

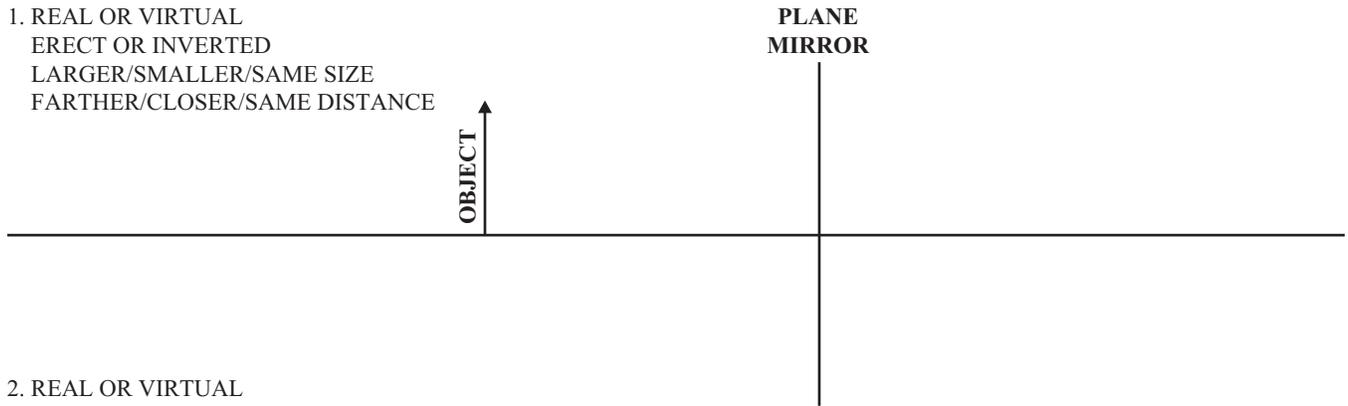
Chapter 19

Light: Geometric Optics

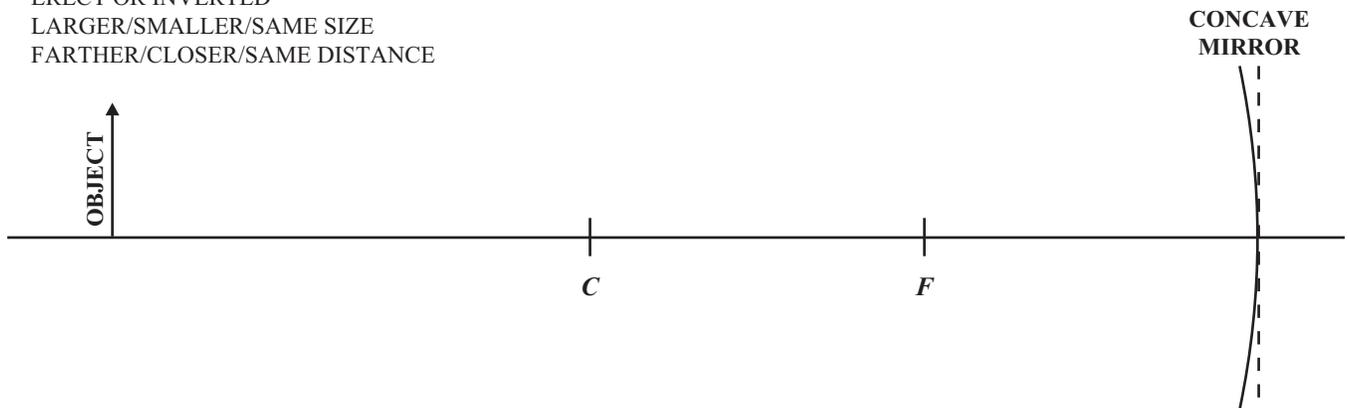
19.2 Ray Diagrams for Mirrors

Homework # 152

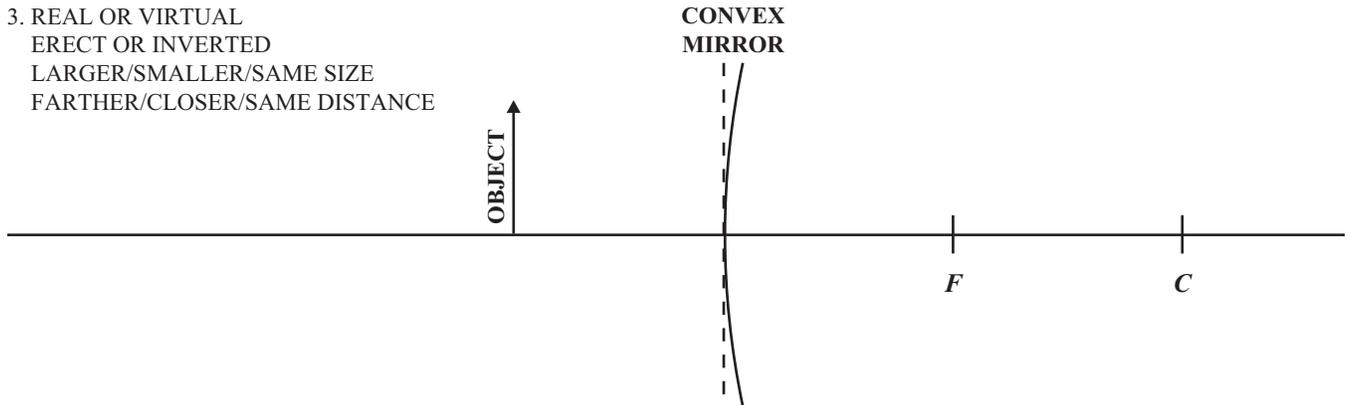
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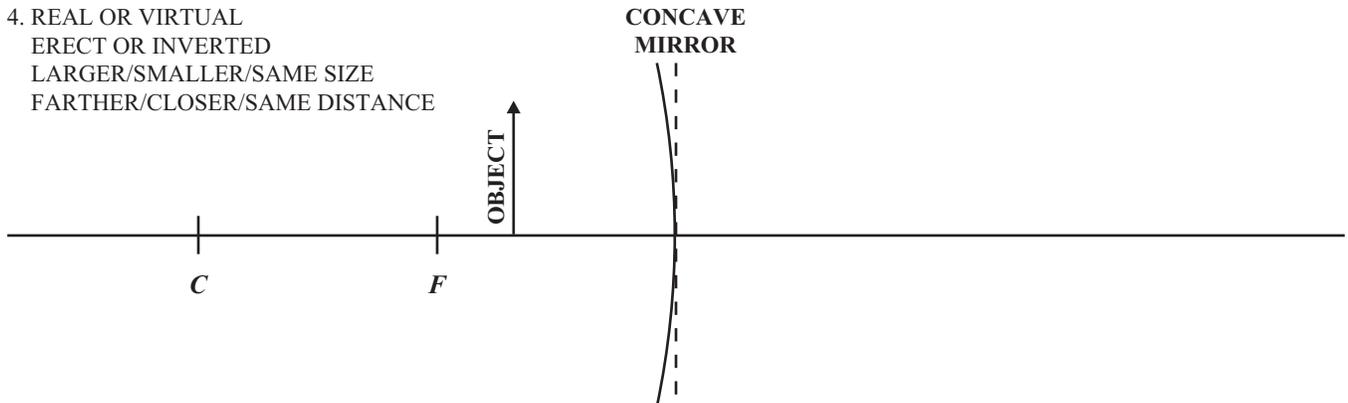
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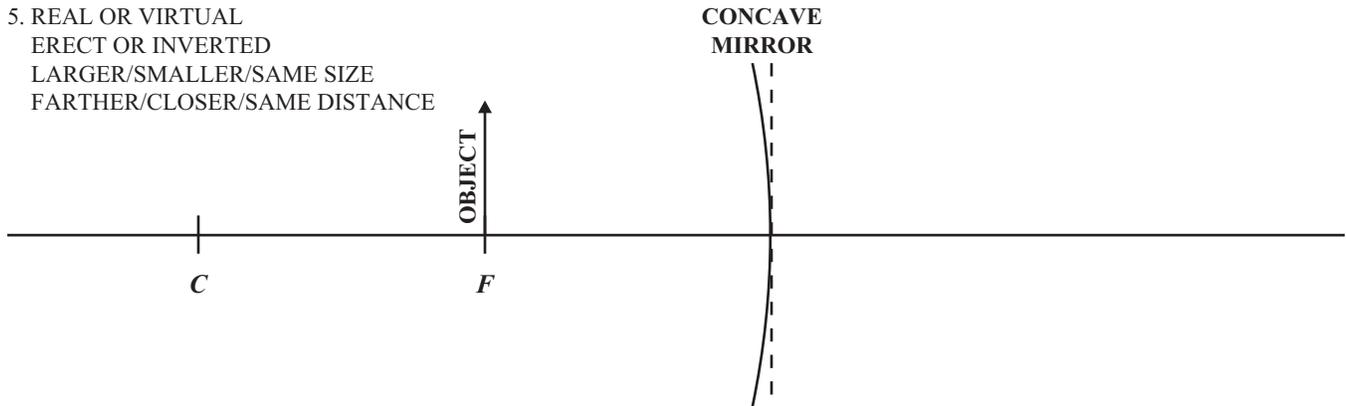
Chapter 19

Light: Geometric Optics

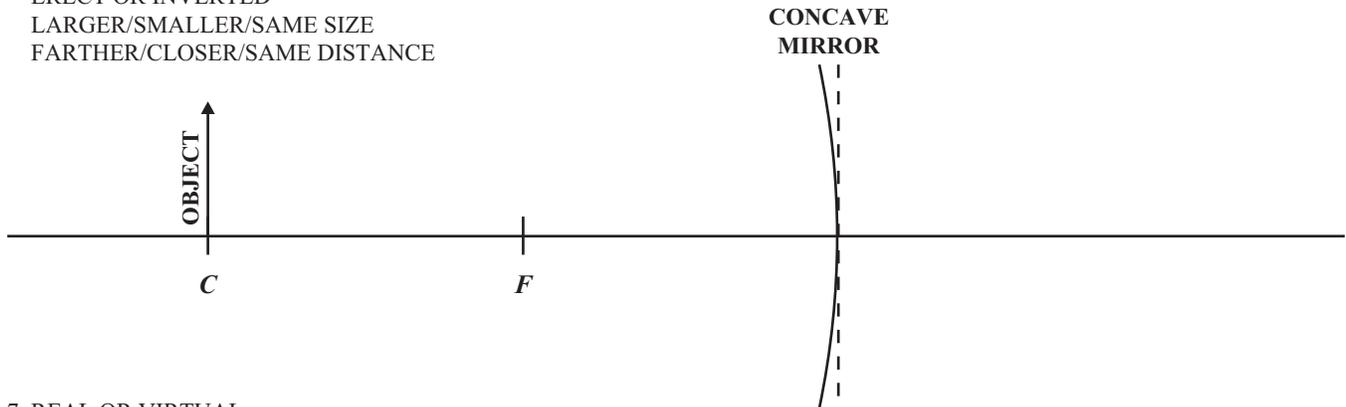
19.2 Ray Diagrams for Mirrors

Homework # 153

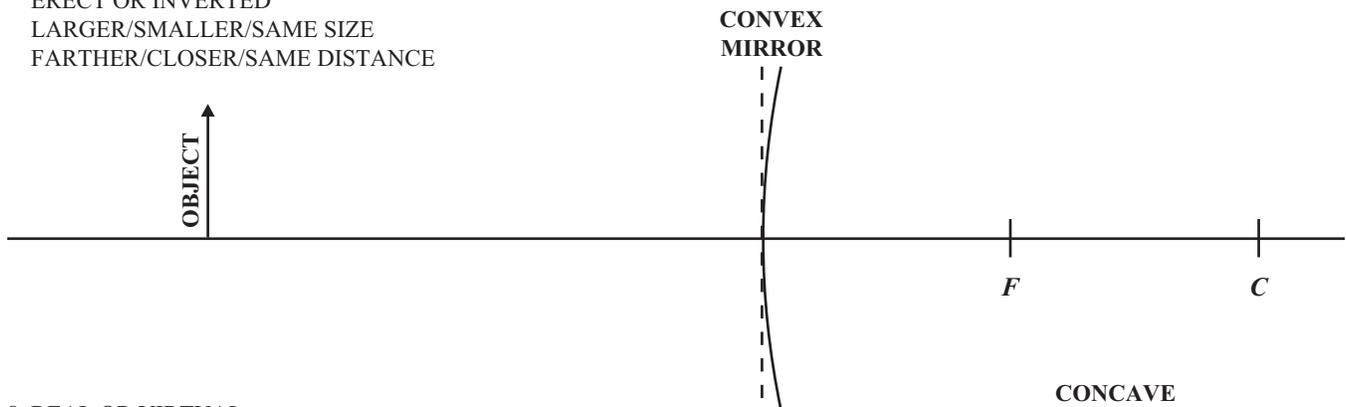
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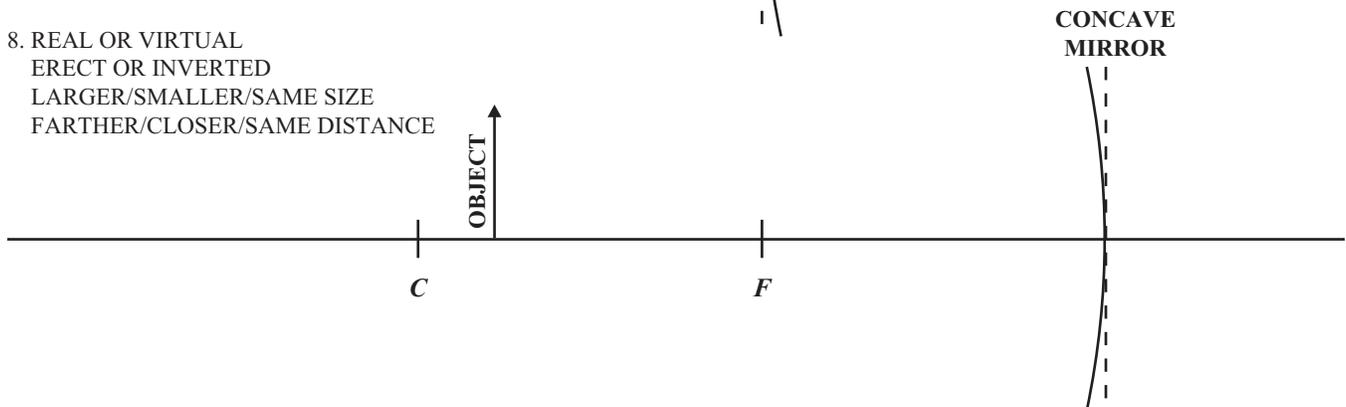
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7. REAL OR VIRTUAL
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8. REAL OR VIRTUAL
 ERECT OR INVERTED
 LARGER/SMALLER/SAME SIZE
 FARTHER/CLOSER/SAME DISTANCE



Chapter 19

Light: Geometric Optics

19.3 Image Formation by Plane and Spherical Mirrors

Homework # 154

I

01. A photographer takes a picture of his own image from a plane mirror that is 3.25 m away. For what distance should the camera lens be focused?
02. Rays from a light source that is very far from a concave mirror are brought to a focus 12.5 cm from the front of the mirror.
 - a.) What is the focal length
 - b.) What is the radius of curvature of the mirror?
 - c.) What is the diameter of the sphere from which the mirror was cut?
03. A 6.25-cm tall object is placed 32.5 cm from a concave mirror with a focal length of 12.5 cm. Is the image _____.
 - a.) real or virtual
 - b.) erect or inverted
 - c.) size larger or smaller than the object
 - d.) located farther or closer to the mirror than the object

II

04. A person whose eyes are 1.64 m above the floor stands 2.25 m in front of a flat mirror that is positioned on a wall such that its bottom edge is 52.5 cm above the floor. When she looks in the mirror, what is the smallest horizontal distance from the base of the wall to the point on the floor that is visible in the mirror?
05. A polished silver ball with a diameter of 78.5 cm is placed on a ceramic pedestal as a lawn ornament. Someone standing 1.85 m away from the ball looks at her image in the ball.
 - a.) How far from the mirror will the image be located?
 - b.) Is the image real or virtual?
 - c.) Is the image easy to see, that is, what is the magnification of the image?
06. A 4.95-cm tall object is placed 44.3 cm from a spherical mirror producing a virtual image 6.25 cm from the mirror.
 - a.) What type of mirror is this?
 - b.) What is the height of the image produced?
 - c.) is the image upright or inverted?
07. A dentist uses a small mirror to be placed inside the mouth so that he can see a patient's teeth easier. One particular mirror produces a 5.25X upright image when placed 2.60 cm from the tooth.
 - a.) What kind of mirror is this?
 - b.) What is the radius of curvature of this mirror?
08. How far from a concave mirror with a focal length of 22.5 cm must an object be placed to produce an image with a magnification of +3.65?
09. How far from a concave mirror with a focal length of 22.5 cm must an object be placed to produce an image with a magnification of -3.65?
10. What is the focal length of a mirror that produces magnification of +0.625 when an object is placed 2.50 m away?

ANSWERS: **01.** 6.50 m **02.** a.) 12.5 cm b.) 25.0 cm c.) 50.0 cm **03.** a.) real ($d_i = 20.3$ cm)
03. b.) inverted ($m = -0.625$) c.) smaller ($h_i = 3.91$ cm) d.) closer ($d_i < d_o$) **04.** 1.06 m **05.** a.) 17.7 cm
05. b.) virtual c.) no ($m = +0.0959$) **06.** a.) convex ($f = -7.28$ cm) b.) 0.698 cm c.) upright ($m = +0.141$)
07. a.) concave ($f = 3.21$ cm) b.) 6.42 cm **08.** 16.3 cm **09.** 28.7 cm **10.** - 4.17 m

Chapter 19

Light: Geometric Optics

19.4 Refraction of Light-Snell's Law

Homework # 155

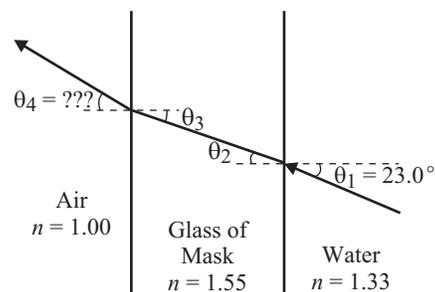
Refer to the table of "Indices of Refraction ($\lambda = 589 \text{ nm}$)" found on [Homework #151](#) in this chapter.

I

01. A beam of light strikes a pane of glass with an index of refraction of 1.50 at an angle of 40.0° with the surface. What is the angle of refraction?
02. A boy dives into a pool, swims to the bottom, and looks up to see the sun at an angle of 18.5° with the normal to the surface. At what angle above the horizon is the sun at this moment?
03. A diver shines an underwater flashlight from the bottom of a lake such that it makes a 36.5° angle with the normal to the surface. At what angle will this light emerge from the surface of the lake?

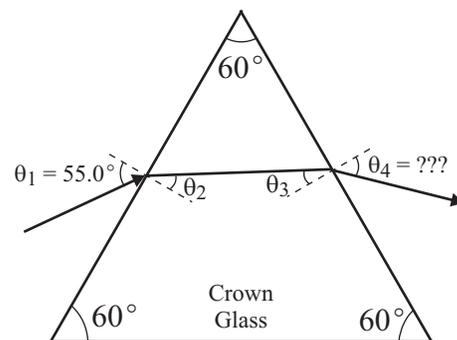
II

04. A bright underwater flood light at the bottom of a 2.75-m deep pool is positioned 1.85 m from one edge of the pool. At what angle will light emerge from the surface of the water at the edge of the pool. Assume the pool is filled to the brim with water.
05. Light reflected from a small object strikes a flat pane of light flint glass at angle of 37.5° with the surface of the pane. At what angle with the surface will light emit from the other side of the pane?
06. A divers mask is made with a flat pane of tempered glass ($n = 1.55$). While underwater, a diver sees an object that is actually located at angle of 23.0° below the level of his eyes. At what angle below the level of his eyes will the diver see the object? See the diagram to the right for the path of a light ray from the water, through the glass of the mask, and into the air that is trapped between the glass of the mask and the diver's face.



Problem 06

07. An equilateral prism made of crown glass is sitting on surface in a room filled with air. A beam of incident light strikes one side of the prism at a 55.0° angle with the normal to the surface as shown in the diagram to the right. Determine the angles in the diagram labeled θ_2 , θ_3 , and θ_4 .



Problem 07

ANSWERS: **01.** 30.7° **02.** 25.0° **03.** 37.7° **04.** 42.1° **05.** $\theta_2 = 30.1^\circ$, $\theta_3 = 30.1^\circ$, $\theta_4 = 52.5^\circ$, $\theta_s = 37.5^\circ$
06. $\theta_2 = 19.6^\circ$, $\theta_3 = 19.6^\circ$, $\theta_4 = 31.3^\circ$ **07.** $\theta_2 = 32.6^\circ$, $\theta_3 = 27.4^\circ$, $\theta_4 = 44.4^\circ$

Chapter 19

Light: Geometric Optics

19.5 Refraction of Light-Critical Angle

Homework # 156

Refer to the table of "Indices of Refraction ($\lambda = 589 \text{ nm}$)" found on [Homework #151](#) in this chapter.

I

01. A diamond is dropped in a bathtub filled with water. What is the critical angle for light exiting the diamond?
02. The critical angle for a certain liquid-air surface is 47.3° .
 - a.) What is the index of refraction of this liquid?
 - b.) What is the possible identity of this unknown liquid?

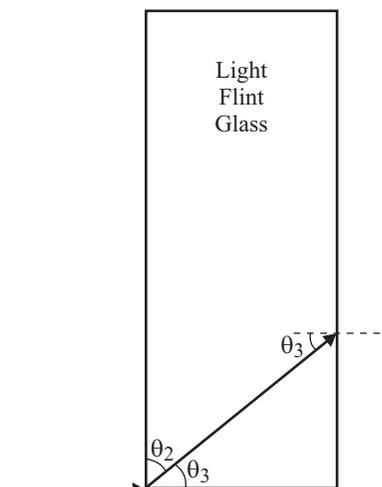
II

03. A beam of light is shown through the bottom of a beaker filled with an unknown liquid to a depth of 12.0 cm. The beam exits the surface of the liquid 11.0 cm horizontally from a point directly above the source of the light.
 - a.) What is the maximum index of refraction of this liquid?
 - b.) If the maximum index of refraction calculated in a.) above is the actual index of refraction, what is the possible identity of this unknown liquid?

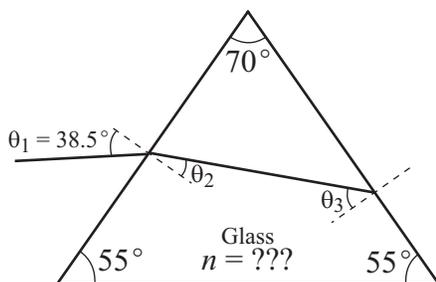
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04. Light strikes the end face of a cylindrical rod made of light flint glass. Show that a light ray entering an end face at any angle will be totally internally reflected. See the diagram to the right.
05. Light strikes one face of a prism creating an incident angle of 38.5° , but is totally internally reflected at the opposite face. If the apex angle is 70.0° as shown in the diagram below, what can be said of the index of refraction of the glass? [Note: The following trigonometric identity may be useful: $\sin(\alpha - \beta) = \sin\alpha \cdot \cos\beta - \cos\alpha \cdot \sin\beta$]

Cylinder-Side View



Problem 04



Problem 05

ANSWERS: **01.** 33.4° **02.** a.) 1.36 b.) Acetone, Ethyl Alcohol **03.** a.) $n \leq 1.48$ b.) Glycerine
04. $\theta_2 = 39.3^\circ$, $\theta_3 = 50.7^\circ > \theta_c = 39.3^\circ$ **05.** $n \geq 1.43$ ($\theta_2 = 25.7^\circ$, $\theta_3 = 44.3^\circ$)

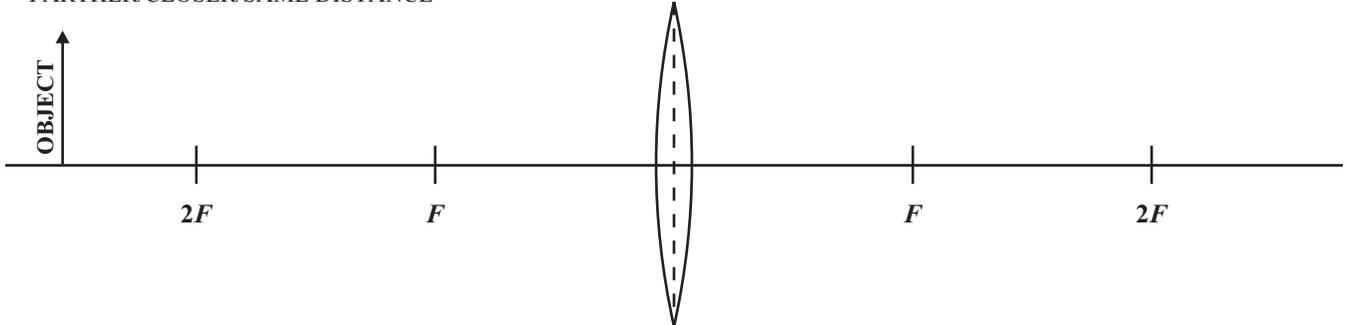
Chapter 19

Light: Geometric Optics

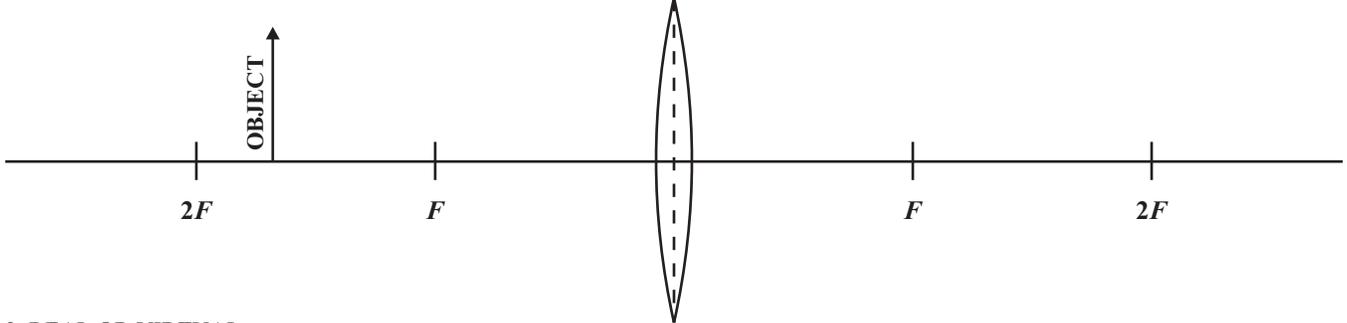
19.6 Ray Diagrams for Lens

Homework # 157

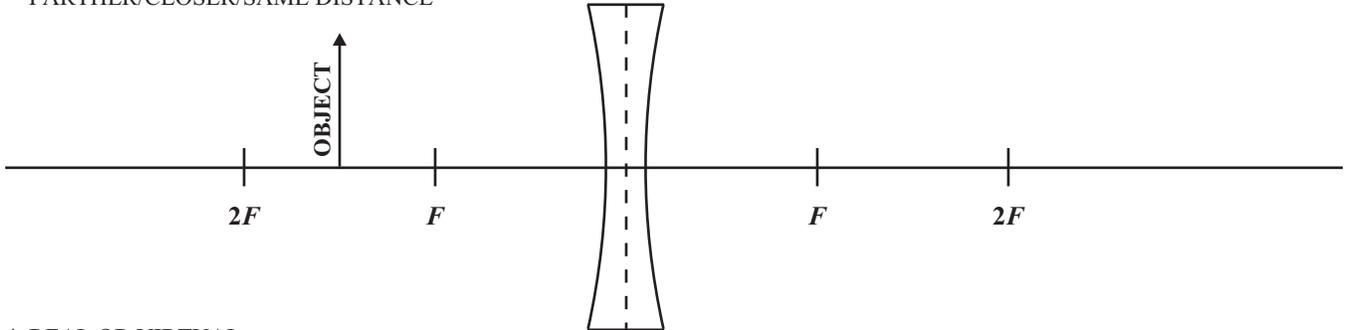
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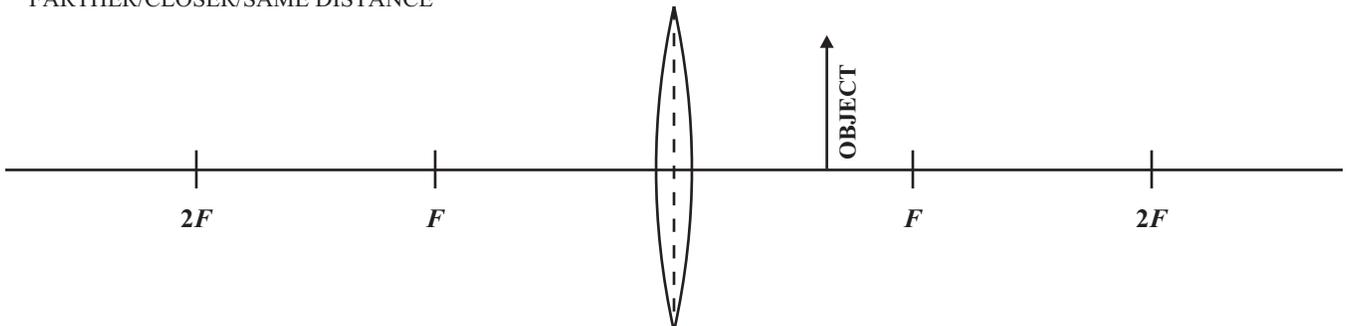
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3. REAL OR VIRTUAL
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FARTHER/CLOSER/SAME DISTANCE



4. REAL OR VIRTUAL
ERECT OR INVERTED
LARGER/SMALLER/SAME SIZE
FARTHER/CLOSER/SAME DISTANCE



Chapter 19

Light: Geometric Optics

19.7 Image Formation by Lens

Homework # 159

I

01. A converging lens with a focal length of 40.0 mm produces an image that is 47.5 mm from the lens. If this image is on the side of the lens opposite that of the object, how far away from the lens is the object located?
02. A bird's feather is placed 94.3 cm in front of a concave lens with a focal length of 850.0 mm. Is the image _____.
- a.) real or virtual b.) erect or inverted c.) larger or smaller d.) closer or farther
03. A 4.75-cm tall object placed 48.6 cm from a lens produces an image 59.2 cm on the other side of the lens.
- a.) What type of lens is being used? b.) What will be the height of the image?

II

04. A magnifying glass (convex lens) with a focal length of 15.0 cm is being used to examine a coin. How far above the coin should the magnifier be held to produce a magnification of +4.50?
05. What is the focal length of a magnifying glass that produces a +5.25 magnification when held 12.5 cm from the newsprint that is being magnified?
06. A +7.50-D lens is held 18.8 cm from an ant. Is the image _____.
- a.) real or virtual b.) erect or inverted c.) larger or smaller d.) closer or farther
07. A -7.50-D lens is held 18.8 cm from an ant. Is the image _____.
- a.) real or virtual b.) erect or inverted c.) larger or smaller d.) closer or farther
08. The mean distance of the sun from the earth is 1.496×10^8 km. A camera with a 45.00 cm lens ($f = 45.0$ cm) is used to take a picture of the sun. The image of the sun produced on the film has a diameter of 4.194 mm. What is the approximate diameter of the sun?

ANSWERS: **01.** 253 mm (25.3 cm) **02.** a.) virtual ($d_i = -44.7$ cm) b.) erect ($m = +0.474$) c.) smaller
02. d.) closer **03.** a.) convex lens ($f = 26.7$ cm) b.) -5.79 cm **04.** 11.7 cm **05.** 15.4 cm
06. a.) real ($d_i = 45.9$ cm) b.) inverted ($m = -2.44$) c.) larger d.) farther
07. a.) virtual ($d_i = -7.80$ cm) b.) erect ($m = +0.415$) c.) smaller d.) closer **08.** 1.394×10^6 km

Chapter 19

Light: Geometric Optics

19.8 Two-Lens Systems/Lens-Maker's Equation

Homework # 160

II

- An object is located 4.75 m from a simple optical system consisting of two lens. The first lens of this system has a focal length of 100 mm and the second lens, which is 20.0 cm from the first lens, has a focal length of 150.0 mm.
 - What is the image distance for the second lens?
 - What is the magnification of the system?
- What is the focal length of a two-lens system, if the two lenses are 50.0 cm apart and have powers of +5.00 D and -3.60 D?
- What is the power of a two-lens system, if the two lens are touching and have powers of +5.00 D and -3.60 D?
- What is the power of a two-lens system, if the two lens are touching and have powers of +3.00 D and -3.00 D?

Corrective Lenses for the Human Eye

- An ophthalmologist prescribes a lens with a power of -4.75 D for a person's right eye. The eye is 2.10 cm from the lens when this person wears his glasses comfortably.
 - Is this person nearsighted or farsighted?
 - What is this person's far point without glasses?
- A person has a near point of 145.0 cm. What power of reading glasses are needed to read at 25.0 cm? Assume that the distance between the eye and the lens of the glasses are 2.25 cm apart.
- The right eye of a person has a near point of 18.0 cm and a far point of 46.0 cm. An optometrist prescribes contact lenses to correct the far vision so the person can see objects at a large distance away. Contact lenses are in direct contact with the eye (thus the name).
 - What power lens are prescribed?
 - What will the person's near point be with this lens?
- The eyeglasses of a nearsighted person has one lens with a focal length of -30.0 cm and this lens is located 1.85 cm from the eye when the glasses are placed comfortably on the person's face. If this person wishes to switch to contact lenses, what focal length contact lens should be prescribed?
- A particular person has an eye in which the distance between the lens of the eye and the retina is 19.00 mm but the focal length of the lens of this eye is 17.00 mm. What focal length corrective contact lenses should be prescribed to see objects clearly?

Lens-Maker's Equation

- A double-convex lens with an index of refraction of 1.55 is made such that the radius of curvature of one side of the lens is 20.0 cm and the radius of curvature of the other side is 30.0 cm. What is the focal length of this lens?
- A double-concave lens with an index of refraction of 1.63 is made such that the radius of curvature of one side of the lens is 25.0 cm and the radius of curvature of the other side is 32.5 cm. What is the focal length of this lens?
- A concavo-convex lens with an index of refraction of 1.52 is made such that the radius of curvature of the concave side of the lens is 15.0 cm and the radius of curvature of the convex side is 22.5 cm. What is this lens' focal length?

ANSWERS: **01.** a.) -28.1 cm b.) $m = +0.0593$ **02.** -14.4 cm **03.** 1.40 D **04.** $P = 0$ ($f = \infty$)
05. a.) nearsighted b.) 23.2 cm **06.** +3.70 D **07.** a.) -2.17 D b.) 29.6 cm **08.** -3.14 D **09.** -161.5 mm
10. 21.8 cm **11.** -22.4 cm **12.** -86.5 cm